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Energy Procedia 68 (2015) 68 – 76

Energy Procedia

2nd International Conference on Sustainable Energy Engineering and Application, ICSEEA 2014

Pre-installation design simulation tool for grid-connected photovoltaic system using iterative methods

Nur Dalilah Nordin[a], Hasimah Abd Rahman[a,*]

[a]*Centre of Electrical Energy Systems, Universiti Teknologi Malaysia, 81310 Johor, Malaysia*

Abstract

The paper presents a simple technique in pre feasible design of grid-connected photovoltaic systems for the application in all energy sectors. A user-friendly simulation tool named Pre-Installation Design for GCPV (PIDGCPV) was developed to assist PV installer or any energy consumer in preliminary evaluation on PV system sizing to avoid over/under size of system. The developed simulation tool uses an iterative method embedded in Macro Excel integrated with Microsoft Visual Basic application. The simulation tool covers three constraints, which are space, energy requirement and budget. The iterative method is used for the selection of optimal number of photovoltaic (PV) module and inverter for a proposed system. In addition, a database for PV modules, inverters, and meteorological data for each state in Malaysia is also embedded in the software. The analysis shows straightforward comparison between the simulated result and the actual installed data based on the constraint selection. It indicates that the capability of the developed simulation tool is giving higher accuracy and can be used as pre installation design tool.

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Peer-review under responsibility of Scientific Committee of ICSEEA 2014

*Keywords:*o ptimal sizing; pre-designed simulation tool; grid-connected; photovoltaic; renewable energy

1. Introduction

Renewable energy technology produces clean and sustainable energy from renewable sources such as sun, wind, and water flow. Photovoltaic (PV) technology is one of the most promising technologies and if it properly utilized, it

* Corresponding author. Tel.: +607-5557004; fax: +607-5557005.
E-mail address: hasimah@fke.utm.my

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Peer-review under responsibility of Scientific Committee of ICSEEA 2014
doi:10.1016/j.egypro.2015.03.234

able to fulfill world demand [1]. Based on [2], PV industry has grown more than 40% per year since last decades, due to rapid decrease in PV system cost. There are two main applications for PV system, which are grid-connected PV system (GCPV) and stand-alone PV system (SAPV). GCPV system integrate PV technology with main grid, meanwhile SAPV is an off grid system, where PV technology is not connected to utility network. In GCPV system, PV modules generate DC power, and inverter is used to convert DC to AC power output. GCPV system has numbers of advantages; modularity system, less maintenances, environmental friendly [3] and the excess energy can be sold to utility [4], which entitled for bill reduction.

Even though GCPV potential is proven, one of the most important issues in the implementation of GCPV is the accurate system sizing; improper sizing will lead to either over sizing or under sizing the system and later give significant impact to the investment. Additionally, the system that is properly sized usually based on specific site's meteorological condition and accurate selection of components. Although assorted models of PV modules of various technologies available in current market, still the difficulty in selecting the best combination of PV modules and inverters is faced by the energy installer. Hence, an accurate pre-sizing tool for PV system installation is vital for the PV system component manufacturers, research and development teams, systems integrators and end customers. Such reliable tool is critical for the continuing development of the PV industry and also key metric in helping to identify future needs [5].

Simulation tools are one of the most common methods to understand PV generation potential at a given location within expected operation constraint. There are seven main categories of computer simulation tools available in current market, such as performance simulation tools, economic evaluation tools, photovoltaic industry related tools, analysis and planning tools, monitor and control tools, site analysis tools and solar radiation maps [6]. Nowadays, discrete type of simulation programs are available to simulate or predict power system performances using meteorological algorithm or meteorological database, provide economic analysis, system planning, design, sizing and optimize energy sources. Even though many sizing simulation tools have been introduced, the system designers are required to indirectly utilize the sizing algorithm embedded in the software. Hence, the existing software usually used as comparison tool to manually calculated system design [4].

This paper presents a new user-friendly simulation tool, known as PIDGCPV. It was developed in order to assist energy consumers or energy installer to determine the optimum configuration of GCPV system. The software is suitable for pre-installation design, and will be an optimization tool for a pre-selected PV module type, inverter type, and pre-defined constraint by the user. The analysis gives straightforward comparison between the simulated result and the actual installed data based on the constraint selection. Also the economic and performance analysis for the system installed can be obtained by employing PIDGCPV simulation tool.

2. Overview of simulation methods

This section presents the overview of GCPV system sizing, economic analysis and performance analysis simulation. A block diagram to represent system flows in Pre-Installation Design for GCPV is shown in Fig. 1. It consists three main parts, which are user input section, database section, and calculation section.

Initially, the user, energy installer or consumer has to select the types of PV module, inverter, site location and system constraint. PV module, inverter, and site location is chosen based on selection menu generated from database embedded in the simulation tool.

For PV module and inverter database their database were created through survey from the available products in the market. There are 100 different types of PV modules and 162 types of inverters selections recorded in database. Meanwhile, meteorological database for each state in Malaysia was developed by extracting and downloading the related meteorological data of Meteonorm 6.1, using PVsyst V6.10 software [7]. PVsyst V6.10 is a commercialize software that mainly used as an analysis, planning, design, and sizing tool. This software has its own Meteo database, and able to import data from website. Meteonorm 6.1 is a comprehensive meteorological reference that has a meteorological forecast model to calculate hourly and minute value from monthly data for any sites.

The databases are also equipped with technical data needed during sizing calculation. The technical data provided in databases are listed as Table 1.

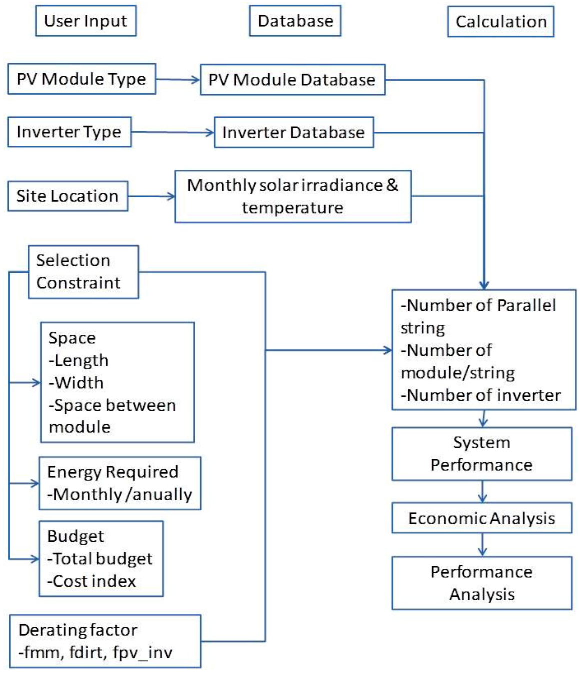

Fig. 1. Block diagram of simulation steps.

Table 1. Technical data provided in databases.

PV module database	Inverter database	Site Meteorological database
Module brand	Inverter brand	Solar radiation
Module type	Inverter type	Ambient temperature
Module dimension	Nominal output power	
Maximum power	Maximum power	
Maximum power voltage	Maximum voltage	
Maximum power current	Maximum window voltage	
Open circuit voltage	Minimum window voltage	
Short circuit current	Maximum DC input current	
Temperature coefficient	Efficiency	

After PV module, inverter, site location and system constraint selection, user needs to define constraint variables and derating factor value. After that, the software will automatically calculate optimum number for module's parallel string, optimum number of module in each string, and number of inverter needed. Software's calculation is started by determine PV modules quantity needed to fulfil pre-set system constraint. Afterwards, range of PV modules in a string and maximum modules' parallel string is computed. Later, the simulation tools will generate all possible PV array configuration within the range of PV modules in a string and maximum parallel strings iteratively. The best combination that able to fulfil system constraint is selected as the most favourable design.

Subsequently, the software will calculate annual system performance. After that, user sets the value for GCPV components cost and net discount rate in order to determine proposed system's economic analysis. Finally, performance analysis for each month is determined and it also being displayed in a form of graph.

3. Software development

The simulation tool known as Pre-Installation Design for GCPV (PIDGCPV) was developed using Microsoft Excel based spreadsheet model with Visual Basic for Application (VBA) coding. It enables all users and designers to establish the most suitable GCPV system configuration (PV module and inverter) based on project constrain and also able to determine project's economic analysis automatically. In order to make the program user-friendly, vertical menu function and pop-up menu were developed. The objectives in developing this software are:

- To find optimum configuration and pre-installation design of GCPV system in Malaysia that able to meet all predefined constraints in the project.
- To optimize system configuration and arrangement for a pre-selected PV module and inverter type.
- To perform economic analysis and performance analysis for the proposed GCPV system.

4. Pre-installation GCPV result and discussion

The software was divided into three main functions, categorized by space constraint function, energy requirement constraint, and budget constraint. In this section, two reports from installed GCPV system in Malaysia were selected and compared to simulation results [8, 9].

Fig. 2 displays the main page of PIDGCPV software. First, users need to select the type of PV module and inverter model. Then, follow by selecting the type of constraints (space, energy or budget) and data has to be inserted by users. The users also need to specify the values for system derating factors and site system location. Here, the users have option, either input specific value for temperature derating factor and predicted cell temperature, or use default value which already in the system. The final step is the optimum inverter to PV array ratio, which was calculated automatically.

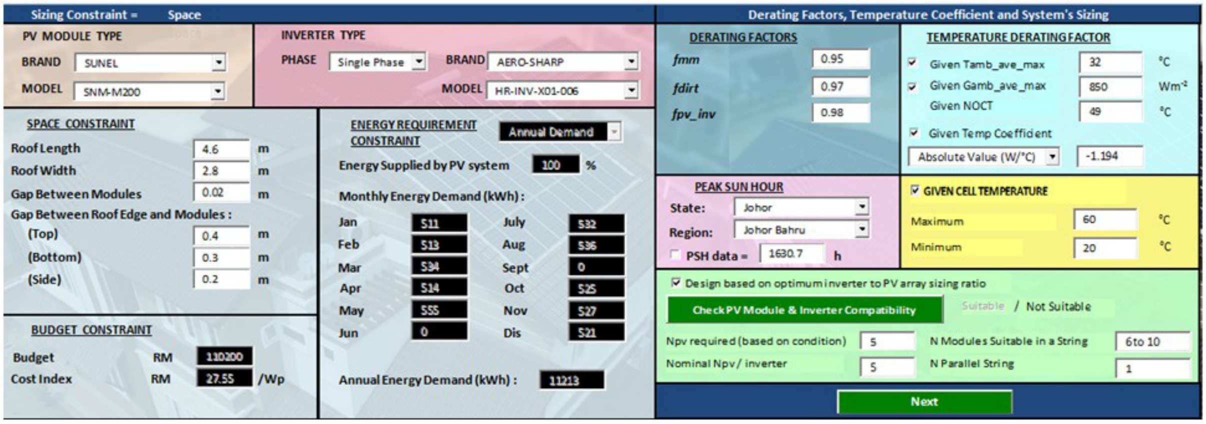

Fig. 2. PIDGCPV main page.

Fig. 3 presents the sizing results calculated using the PIDGCPV software after all the required data were keyed in. First column indicates the maximum number of modules required to fulfill system constraint selected. Second column represents optimum modules distribution for the prior selected inverter. Third section shows the results for the optimum configuration for the proposed system, based on the predefined constraints, and the forth column displays the annual energy generated, energy yield and the performance ratio of the system.

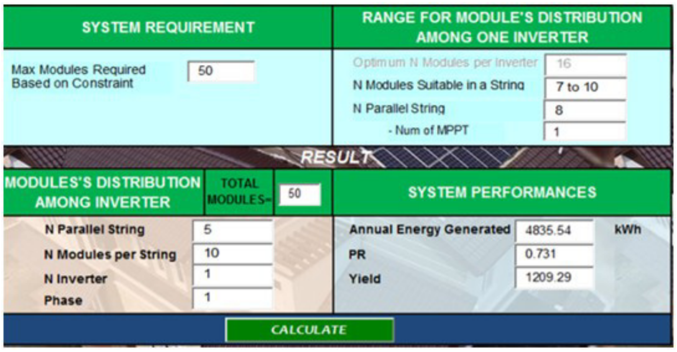

Fig. 3. PIDGCPV analysis results based on selected constrain.

PIDGCPV software tool also displayed the system design configuration as shown in Fig. 4. It shows the optimum modules arrangement at specified space, and also proposed module arrangement for selected inverter. Fig. 5 shows detailed economic analysis for the proposed system, and Fig. 6 presents the monthly performance ratio of the system for a year, monthly graphical representation of energy generated in relation to PSH and also performance ratio in relation to ambient temperature.

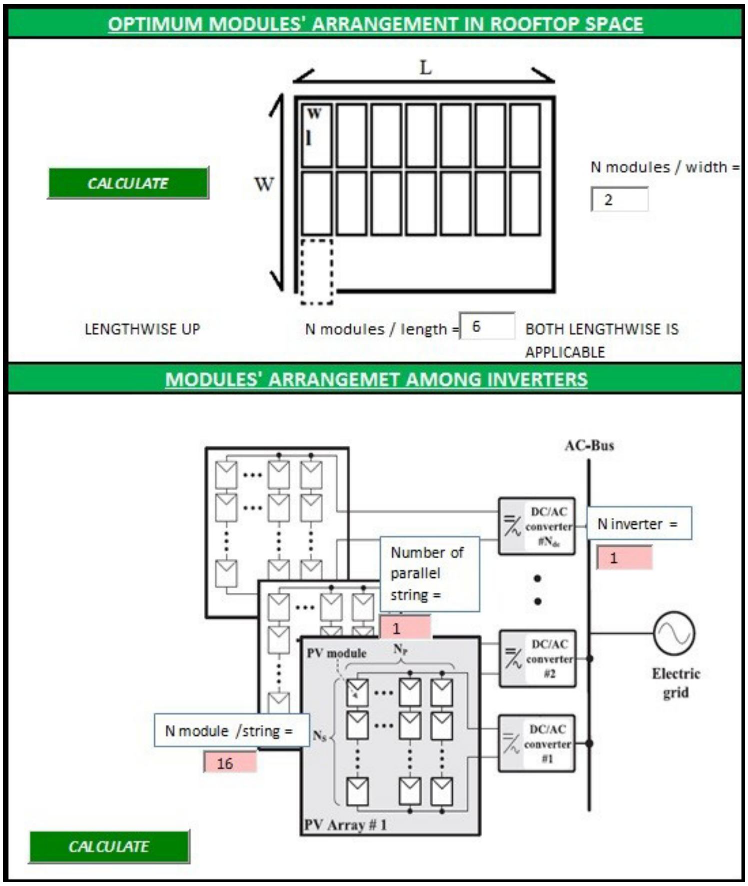

Fig. 4. Optimum modules arrangement.

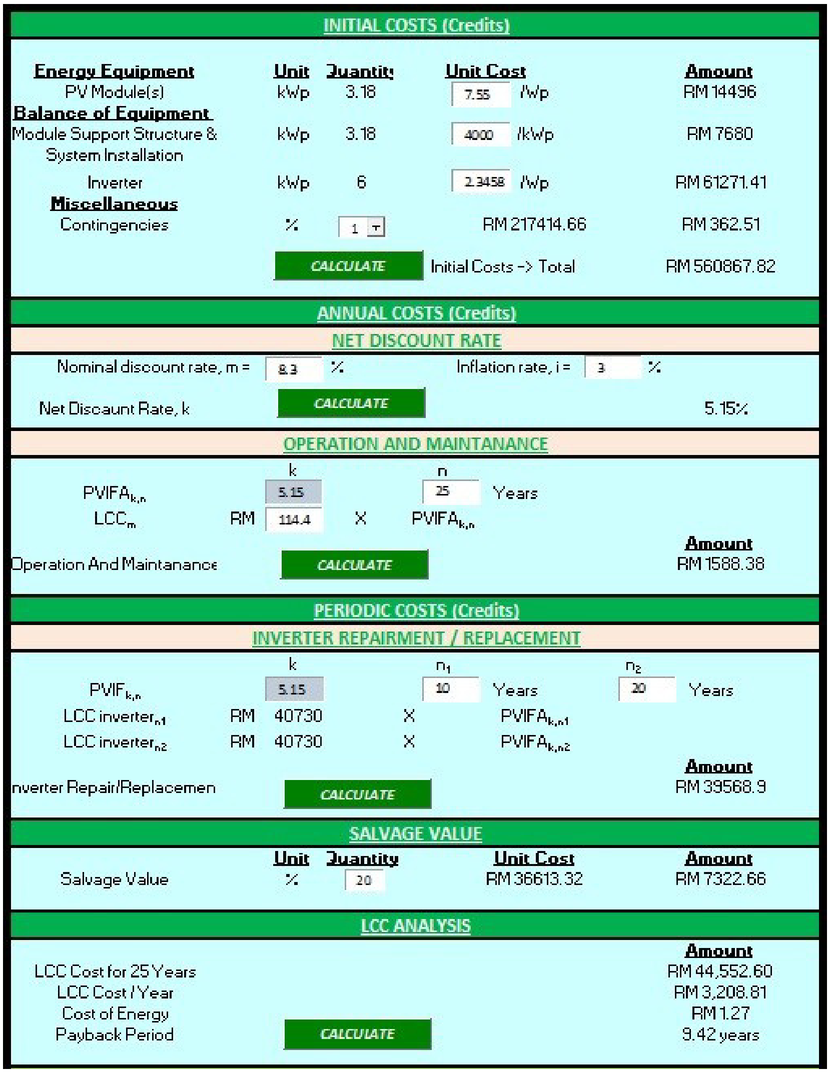

Fig. 5. Results of the economic analysis.

Month	PSH (h)	Temp (°C)	Egenerated (kWh)	Performance Ratio
January	126.9	25.5	384.8713	0.758
February	138.4	26.1	418.5329	0.756
March	156.5	27	471.2057	0.753
April	150.2	27.7	450.697	0.75
May	151.3	28.1	453.1113	0.749
June	140.9	27.5	423.2038	0.751
July	151.1	27.3	454.2829	0.752
August	147.4	27.2	443.3748	0.752
September	141.3	27	425.4401	0.753
October	138.7	26.6	418.4244	0.754
November	117.4	26.2	354.8553	0.756
December	115.2	25.6	349.2179	0.758
Year	1675.3	26.8	5049.0674	0.753

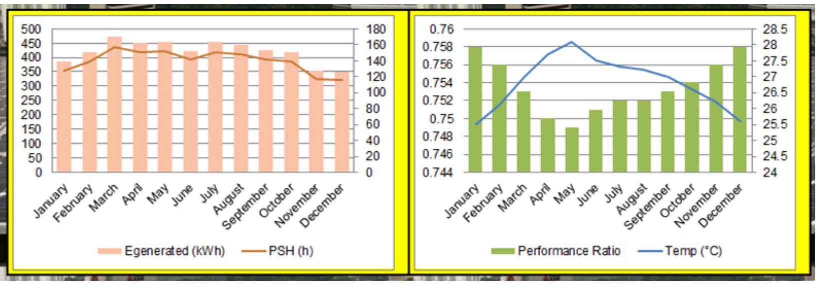

Fig. 6. Results of the performance analysis.

4.1. Space constraint analysis

The optimal sizing's simulation analysis using the developed PIDGCPV software for space constraint is validated using existing building integrated photovoltaic (BIPV) system in [8], from project 4.0 kWp BIPV system at Bungalow House, Damansara. The project is installed on 13th March 2007. The report states that 50 units of Shell Solar 80-C CIS connected to Fronius IG40 inverter were installed on rooftop with 25 x 2 units' arrangement, within around 43m^2 roof area. Hence, by roughly calculated, the mounting area dimension should be 16.4m x 2.7m.Therefore, by using these data, system configuration is simulated and the results are simplified in Table 2.

Table 2. Simulation result for space requirement.

	Simulation Result	Report
Space area	16.4m x 2.7m	43m^2
Module arrangement	25 x 2 unit (lengthwise up)	25 x 2 unit
Maximum modules to optimize space constraint	50	
Number of module suitable in a string	6 to 10	
Maximum number of parallel string	8	
Optimum number of inverter	1	1
Optimum number of module in a string	10	10
Optimum number of parallel string	5	5
Total number of modules	50	50
Annual average energy output	4,835.54 kWh	4,642 kWh
Performance Ratio	0.731	
Yield	1,209.29 kWh/kWp	
Cost of Energy	RM 0.80	
Payback Period	7.38 years	

As mentioned, PV modules covered roof area around 43m^2. Based on that information, a simulation for space constraint was done and optimum PV module arrangement is 25 X 2 units, organized in lengthwise up arrangement. Maximum numbers of PV modules to be mounted at the proposed area are 50 units. The result obtained conform within the range number of modules in a string suitable to be connected to Fronius IG40 is from 6 to 10 units, and maximum modules' parallel strings are 8 connections calculated using PIDGCPV.

The capability of this simulation tool is that it able to generate all possible PV array configurations within the calculated PV modules range in a string and maximum modules' parallel strings iteratively. The best configuration to fulfill space constraint is identified as stated in column 3 (refer Fig. 3) as optimum design (1 unit of inverter, 10 units of PV module in a string, and 5 parallel strings). Afterwards, performance analysis and economic analysis were calculated. Annual average energy output from simulation almost similar to the report, where simulation output is 4,835.54 kWh and energy output reported is 4,642 kWh. Performance ratio obtained is 0.731 and annual yield is 1,209.29 kWh/kWp. In economic analysis, cost of energy for the system is RM 0.80 with a payback period of 7.38 years.

4.2. Energy constraint analysis

The optimal sizing result of GCPV system using energy constraint from developed software is compared to report from installed BIPV system in [9]. The 9.9 kWp BIPV system is installed on shop lots roof at Damansara on 2nd February 2007. Based on the record, expected annual energy requirement is 11,213 kWh. PV modules used in the project is Solarworld SW 165 monocrystaline and Fronius IG30 for the inverter. There, a combination of 60 modules and 1inverter were used to supply energy required. Accordingly, by employing the same data such as the types of PV module, and inverter at a specified site location, a simulation using PIDGCPV software was conducted and the results are simplified using following Table3. From simulation results, minimum PV modules required to fulfil energy requirement is 57 units. Besides, range number of modules in a string suitable to be connected to Fronius IG30 is from 7 to 10 units, and maximum modules' parallel strings are 2 connections.

Iteratively, the simulation tools will generate all possible PV array configurations within the calculated PV modules range in a string and maximum modules' parallel strings. The best configuration to fulfil energy constraint (57 units) is 3 units of inverters, 10 PV modules in a string and 2 parallel strings for each inverter. Therefore, 60 units of PV modules are required to fulfil energy demand.

Table 3. Simulation result for energy requirement.

	Simulation Result	Report
Minimum modules to fulfill energy requirement	57	
Number of module suitable in a string	7 to 10	
Maximum number of parallel string	2	
Optimum number of inverter	3	3
Optimum number of module in a string	10	10
Optimum number of parallel string	2	2
Total number of Modules	60	60
Annual average energy output	11,400.48 kWh	12,136 kWh
Performance Ratio	0.734	
Yield	1,150.91 kWh/kWp	
Cost of Energy	RM 0.79	
Payback Period	7.71 years	

Afterwards, performance analysis and economic analysis were calculated. Annual average energy output from simulation results has small difference, where the output is 11,400.48 kWh (simulation) compared to 12,136 kWh from report. Performance ratio obtained is 0.734 and annual yield is 1,150.91 kWh/kWp. In economic analysis, system cost of energy is RM 0.79 and payback period is 7.71 years.

4.3. Budget constraint analysis

The optimal sizing analysis with budget constraint using the developed PIDGCPV software is also validated using existing system in [8]. Based on the record, GCPV system budget is RM 110,200 and cost of energy for the system is RM 27.55. Based on the report, 50 modules Shell Solar 80-C CIS and 1 unit of Fronius IG 40 were purchased. By using the same PV module type, inverter type and site location, a simulation was done using Pre-Installation of GCPV software and the results are tabulated in Table 4.

Table 4. Simulation result for budget requirement.

	Simulation Result	Report
Maximum modules to optimize budget limit	50	
Number of module suitable in a string	6 to 10	
Maximum number of parallel string	8	
Optimum number of inverter	1	1
Optimum number of module in a string	10	10
Optimum number of parallel string	1	1
Total number of Modules	50	50

The simulation results indicate that the minimum number of PV modules that is affordable within the budget constraint are 50 units. As explain in Space Constraint Analysis section, number of modules in a string suitable to be connected to Fronius IG40 is within 6 to 10 units range, and maximum modules' parallel strings are 8 connections.

The best configuration for defined budget constraint is iteratively selected. 50 units of PV modules and one inverter combination (10 PV modules in a string and 1 parallel string) are the most suited to budget provided for 4.0 kWp system project at Bungalow House, Damansara. Performance analysis and economic analysis results is the same as the results obtained in Space Constraint Analysis section previously.

5. Conclusion

The Pre-Installation Design for GCPV (PIDGCPV) simulation tool has been presented indicating the capability of the tool. The analysis shows that PIDGCPV able to assist energy consumers, energy installer and solar developer in selecting the most suitable module and inverter as well as optimal configuration of the system using iterative method. Also an economic and performance analysis for the installed system is also presented. The analysis shows that the developed simulation tool able to perform accurate pre sizing tool for PV system installation in GCPV system design, sizing and techno-economic analysis which is vital for the PV system component manufacturers, research and development teams, systems integrators and end customers. Such reliable tool is critical for the continuing development of the PV industry and also key metric in helping to identify future needs.

Acknowledgements

The authors wish to acknowledge the supports for this research paper received from Malaysian Ministry of Higher Education (MOHE) and Universiti Teknologi Malaysia through Research University Grant (GUP) Vot No:07H54.

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